Korean Society of Surveying, Geodesy, Photogrammetry, and Cartography 2006 / Chuncheon / Korea

베트남 메콩강 삼각주 지역의 중금속 오염도 평가를 위한 모형 개발
Application of GIS for estimation of heavy-metal oriented pollution at the Mekong river in Vietnam

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Abstract

습지나 얕은 바다에 존재하는 중금속의 분포를 모델링하는 것은 그 곳의 생태계를 보존하기 위해 꼭 필요한 일이다. 본 연구에서는 GIS(Geographic Information System) 기법 및 위성영상, 실제 대상지역 측량자료를 이용하여 베트남의 동남쪽에 있는 메콩강 삼각주 지역의 중금속 분포를 예측하는 기법을 제안하였다. 이를 위해 중금속의 분포에 영향을 미치는 공간적 요소(Spatial factor)와 구조적 요소(Structural factor)를 통계적으로 처리함으로써 대상지역에 대한 As(arsenic) 오염도를 예측하였다. 또한 중금속 오염되었다고 평가된 지역을 위성영상을 이용하여 표현함으로써 본 연구의 결과를 시각적으로 제시하였다.

1. Introduction

The Mekong river is the biggest in the southeast Asian region. It stretches across six countries including China, Myanmar, Laos, Thailand, Cambodia, and Vietnam. Mekong delta area consists of three parts. They are cities which occupies 10% of the whole area, agricultural land which covers 83%, and wetland which occupies 7%. The population of Mekong river area was 16.9 million in 1996. With the 15,000m^3/s flow rate, the Mekong river transports large amount of material to the open sea in southeast Vietnam. The material mostly consists of alluvium, and also contains industrial wastes. They are polluting wet land and coastal zone of Mekong area. Thus, it is important to model and predict the behavior of industrial wastes.

This paper is mainly concerned with the distribution of heavy metal distribution modelling, and gives an experimental result that estimates As(arsenic) pollution around Mekong area. GIS techniques were used to aid this estimation. GIS factors were divided into two kinds of groups. One is the group of spatial factors, and the other is of structural factor. Satellite images were also used to identify the distribution of heavy metal. Finally, this paper presents the map that shows heavy metal pollution in Mekong using statistical methods such as Chi-square, GIS fuzzy, and pair-wise comparison.

2. Algorithms

2.1 Data description

In this paper, we used the analysis result of samples taken at 768 stations on May 2002 in the Mekong river. The samples comprised of 448 for water quality analysis, 512 for slit component analysis, 443 for carbonate property analysis, and rest of them for the analysis of environmental properties such as ph, salty index, Eh, etc. We also used geological map, geo-chemical map, sedimentary map, and geo-morphologic map.

Distribution of material in the river and deposit environment are two vital factors in the formation of sediment. Thus, GIS factors were divided into kinds of groups which are spatial and structural factors. Spatial factors were used to analyze the distribution and structural factor to analyze the environment. Structural factors were assumed to affect each graphic unit. In other words, its influence is confined within a graphic unit boundary. The structural factors contribute to the understanding of deposit environment of heavy metal. With respect to the spatial factors, they were measured in the following three ways: absolute location, relative location, and neighborhood effect. The spatial factors contribute to the understanding of distribution of heavy metal which help us to recognize the coordinates of sampling station, and distance between a station and a sediment strata.

Satellite images from MODIS were also used to detect the annual quantitative and qualitative change of wetland forests in the study area.

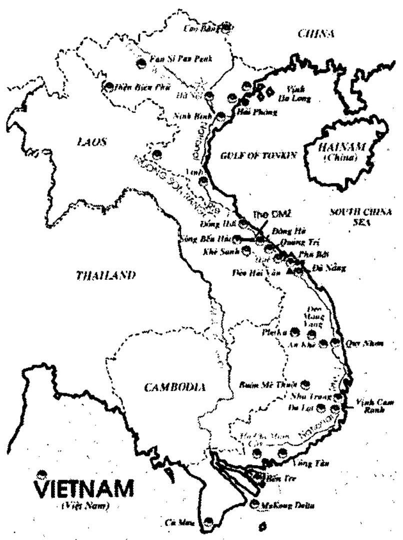

Figure 1. The study area and sample stations

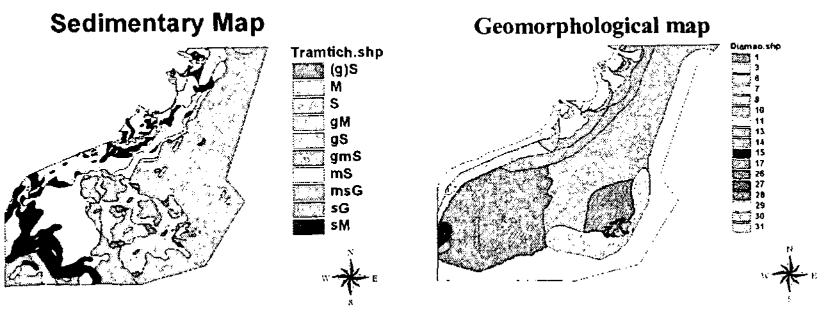

Figure 2. Examples of structural factor

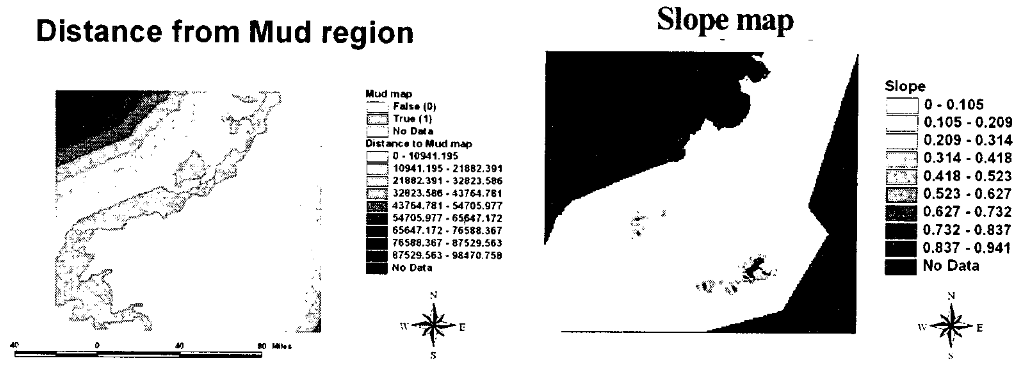

Figure 3. Examples of spatial factors

2.2 GIS spatial data analysis

The research procedure is as follows to perform proper GIS analysis.

1) First of all, the main factors used for this paper are selected and conceptual descriptions of these factors are performed.

2) The second step continues with the classification of these factors and the investigation to find the relationship between them. For this purpose, the Chi-square test was performed, and a contingency table is established to detect the relationship. Table 1 shows distribution of heavy metal class according to the distribution of sediment class. The sediment consists of three distinct elements which are Mud (M), Sand (S) and Gravel (G). The heavy metals consist of twelve elements which are Mg, Mn, Cu, Pb and As etc. Using table 1, we can identify whether the distribution of element is related to sediment types.

Table 1. The contingency table

	Mg	Mn	Cu	Pb	Zn	Cd	Sb	As	Hg	Br	I	B	Sum
Mud	152532.825	2.800279	0.316874	0.14642	1.902724	0.00972	0.036758	0.279505	0.003686	7531.806	5.585924	485.2868	**160560.9993**
Sand	90346.7755	1.658634	0.187688	0.086726	1.127003	0.005757	0.021772	0.165553	0.002183	4461.167	3.308601	287.4404	**95101.94676**
Gravel	86520.3999	1.588387	0.179739	0.083053	1.079272	0.005513	0.02085	0.158542	0.002091	4272.227	3.168475	275.2667	**91074.17967**
Sum	**329400**	**6.0473**	**0.6843**	**0.3162**	**4.109**	**0.02099**	**0.07938**	**0.6036**	**0.00796**	**16265.2**	**12.063**	**1047.994**	**346737.1258**

To test whether there is a statistically significant relationship between two classes, we used the ϕ static coefficient: ϕ makes a correction for the fact that the value of χ^2 is directly proportional to sample size. The ϕ is computed with equation (1):

$$\phi = \mathrm{Sqrt}(\chi^2/\mathrm{Total}) \tag{1}$$

The value of ϕ is zero when there is no relationship and 0 to 1 when there is any relationship. From the process, we can find the ϕ value between As and Mud is the maximum in the value list. Clearly, there is a relationship between As element and the Mud sediment in this study area.

Table 2 lists quantities used in equation (1) for the χ^2 test.

	O(i)	E(i)	O(i) - E(i)	[O(i) - E(i)]^2	{[O(i) - E(i)]^2}/2
Mud_Mg	152634	152532.825	101.175	10236.38062	0.067109362
Mud_Mn	1.3654	2.800279	-1.434879	2.058877745	0.735240219
Mud_Cu	0.365	0.316874	0.048126	0.002316112	0.007309252
Mud_Pb	0.1142	0.14642	-0.03222	0.001038128	0.007090072
Mud_Zn	1.894	1.902724	-0.008724	7.61082E-05	3.99996E-05
Mud_Cd	0.00966	0.00972	-6E-05	3.6E-09	3.7037E-07
Mud_Sb	0.03929	0.36758	-0.32829	0.107774324	0.293199641
Mud_As	0.2953	0.279505	0.015795	0.000249482	0.000892585
Mud_Hg	0.00352	0.003686	-0.000166	2.7556E-08	7.47585E-06
Mud_Br	7434.7	7531.806	-97.106	9429.575236	1.251967355
Mud_I	5.713	5.585924	0.127076	0.01614831	0.002890893
Mud_Br	482.75	485.2868	-2.5368	6.43535424	0.01326093
Sand_Mg	90264	90346.7755	-82.7755	6851.7834	0.075838715
Sand_Mn	1.1381	1.658634	-0.520534	0.270955645	0.16336072
Sand_Cu	0.1373	0.187688	-0.050388	0.002538951	0.013527506
Sand_Pb	0.1119	0.086726	0.025174	0.00063373	0.00730727
Sand_Zn	1.161	1.127003	0.033997	0.001155796	0.001025548
Sand_Cd	0.00555	0.005757	-0.000207	4.2849E-08	7.44294E-06
Sand_Sb	0.01966	0.021772	-0.002112	4.46054E-06	0.000204875
Sand_As	0.148	0.165553	-0.017553	0.000308108	0.001861083
Sand_Hg	0.00235	0.002183	0.000167	2.7889E-08	1.27755E-05
Sand_Br	4541.6	4461.167	80.433	6469.467489	1.450173797
Sand_I	3.557	3.308601	0.248399	0.061702063	0.018648989
Sand_Br	290.214	287.4404	2.7736	7.69285696	0.026763311
Gravel_Mg	86502	86520.3999	-18.3999	338.55632	0.003913023
Gravel_Mn	3.5438	1.588387	1.955413	3.823640001	2.407247101
Gravel_Cu	0.182	0.179739	0.002261	5.11212E-06	2.84419E-05
Gravel_Pb	0.0901	0.83053	-0.74043	0.548236585	0.660104493
Gravel_Zn	1.054	1.079272	-0.025272	0.000638674	0.000591764
Gravel_Cd	0.00578	0.005513	0.000267	7.1289E-08	1.29311E-05
Gravel_Sb	0.02043	0.2085	-0.18807	0.035370325	0.169641846
Gravel_As	0.1603	0.158542	0.001758	3.09056E-06	1.94937E-05
Gravel_Hg	0.00209	0.002091	-1E-06	1E-12	4.7824E-10
Gravel_Br	4288.9	4272.227	16.673	277.988929	0.065068857
Gravel_I	3.333	3.168475	0.164525	0.027068476	0.008543061
Gravel_Br	275.03	275.2667	-0.2367	0.05602689	0.000203537
			Sum		7.453114739

Table 2. Lists for the χ^2test

3) The third step is creating the mathematical relationship model between As and Mud in the study area. A sedimentary map consists of polygons of various strata, and a As (Arsenic) geo-chemical dataset is represented as point coverages that have the attributes such as sample locations and associated values. From the initial visual analysis of the As data and mud map, we can find a pattern that As existence is corresponding closely with the presence of mud. The As values are very high in the mud region and they appear to decrease as the distance from the mud region increases. Therefore, we used the 'Near' tool of Arc/GIS 9.0 software to calculate the distances between AS sample stations and mud regions. The figure 4 shows the As values according to the distance from the Mud region.

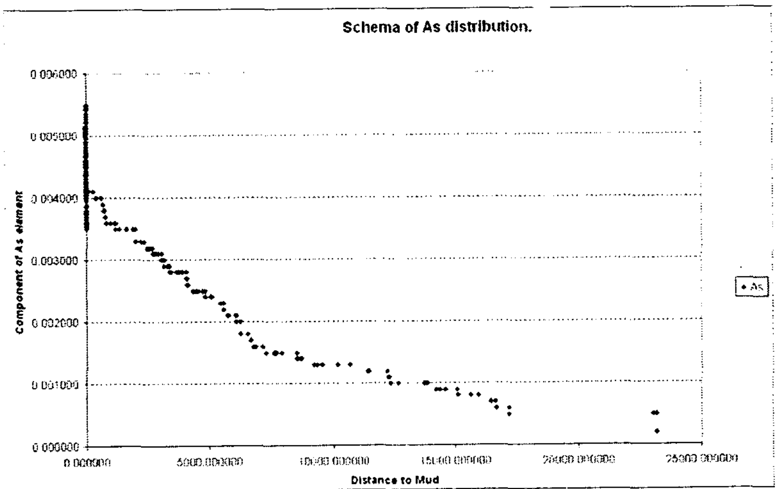

Figure 4. As distribution according to the distance from the Mud region

The mathematical relationship is determined using the Least-square method. In this paper, the As distance sets are divided into 2 parts such that 'distance less than 10,000m' and 'distance farther than 10,000m'. For the variation of As within 10,000m from the mud region, a simple model of the 'quadratic polynomial regression' equation was suggested(see equation (2)).

$$y = a_0 + a_1X + a_2X^2 \quad (2)$$

Where, a0 = 4.00540232658386E-03, a1 = -3.68451480881049E-07, a2 = 9.82724318587813E-12, and in this regression case, the correlation coefficient (r) is 0.732.
For the variation of As farther than 10,000m from the mud region, it was suggested 'polynomial regression' equation(see equation (3)).

$$y = ae^{(bx)} \quad (3)$$

Where: a = 0.5052246466614908, b = -0.5532236835402445, and in this regression case, the correlation coefficient (r) is 0.742.

4) The fourth step continues with the fuzzy processing. Fussy processing is important for the prediction because the modeling with uncertainty requires more than probability theory. In the study area, the dimension of sediment strata and water bodies are consequently varied over time by effect of frequent flood, tidal variation and the gains of the land. Therefore, the geographical entities corresponding to coastal of Mekong river is considered as fuzzy sets. To generate values for these fuzzy entities, the membership function is constructed and shown as equation (3).(Weldon A et al. 2003)

$$\mu_{T(x,y)} = \frac{f[z(x,y)]}{100} \quad (3)$$

Then based on this membership function, the fuzzy set values for each factor is assigned. Table 3 shows the Fuzzy set values for factors.

Table 3. The fuzzy set values table

Factors		1	0 ~ 1
	Slope	0 ~ 5 degree	5 ~ >10 degree
Changable	Distance to Mud	0 m	0 ~ 10,000m
	Age of sediment	Early Quaternary	Mid = 0.7; Late = 0.3
	Morphology	Deposition	Stable = 0.5; Erosion = 0
	Distance to Shoreline	~ 1,000m	1,000 ~ 10,000m
Fixed	Distance to As samples	0m	1 ~ 10,000m
	Distance to residential area	~ 500m	500 ~ 5,000 m

5) The fifth step is determining the weighting values for each factors. The weighting value for each GIS factor was created by the experiment of geologists of Division of Geology & Mineral Marine Geology Survey of Vietnam using the Pair-wise Comparison method. Table 4 shows the weighting values for factors which are considered in this paper.

Table 4. Weight factor

Factors	Weight
Slope	0.10
Distance to Mud	0.20
Distance to residential area	0.15
Age of sediment	0.05
Morphology	0.10
Distance to As samples	0.20
Distance to Shoreline	0.10
Sum	1.00

6) Finally, the As heavy metal pollution is mapped and presented. The As pollution is divided into 7 classes based on the estimation of pollution level in the study area. As shown in figure 5, the implicit pollution region concentrates in the mouth of Mekong river and the deposition area.

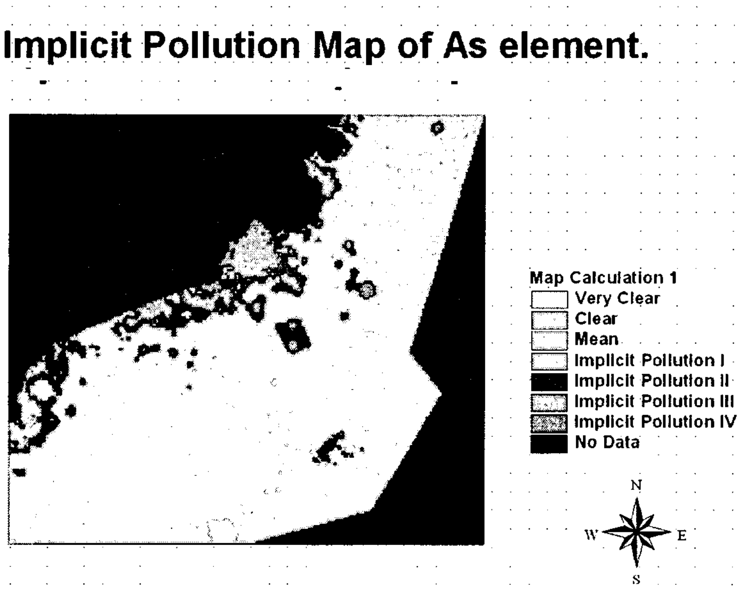

Figure 5. The estimated pollution map of As element
(I: very low level pollution, II: low, III: medium, IV: high)

3. Conclusions and future works

In this paper, the As metal pollution is estimated using spatial and structural factors and remote sensing images. Such estimation techniques can be used for future development projects and it can be also used as a guideline to choose appropriate techniques for management of wetland, inundated forest flows and seaboard. In this area, enormous amounts of information such as the field work data and remote sensing images already exist, but are still in need. Once these further data are acquired, it is allowed for us to create time based analysis and conceptual modeling for seasonal changes with these data.

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